Precision Measurement of CP Violation in $D^0 \to \pi^+\pi^-$ at CDF

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On behalf of the CDF collaboration

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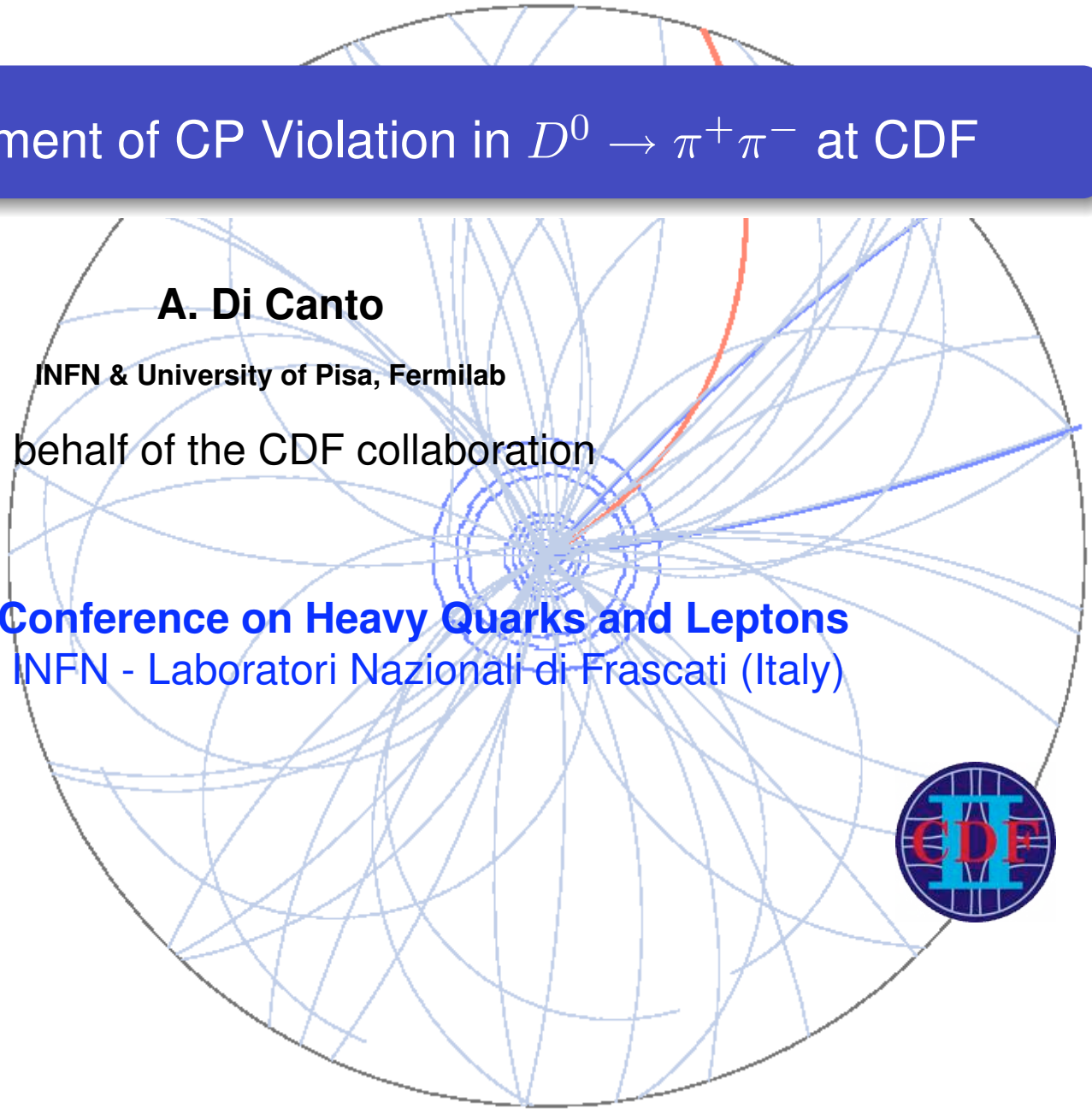
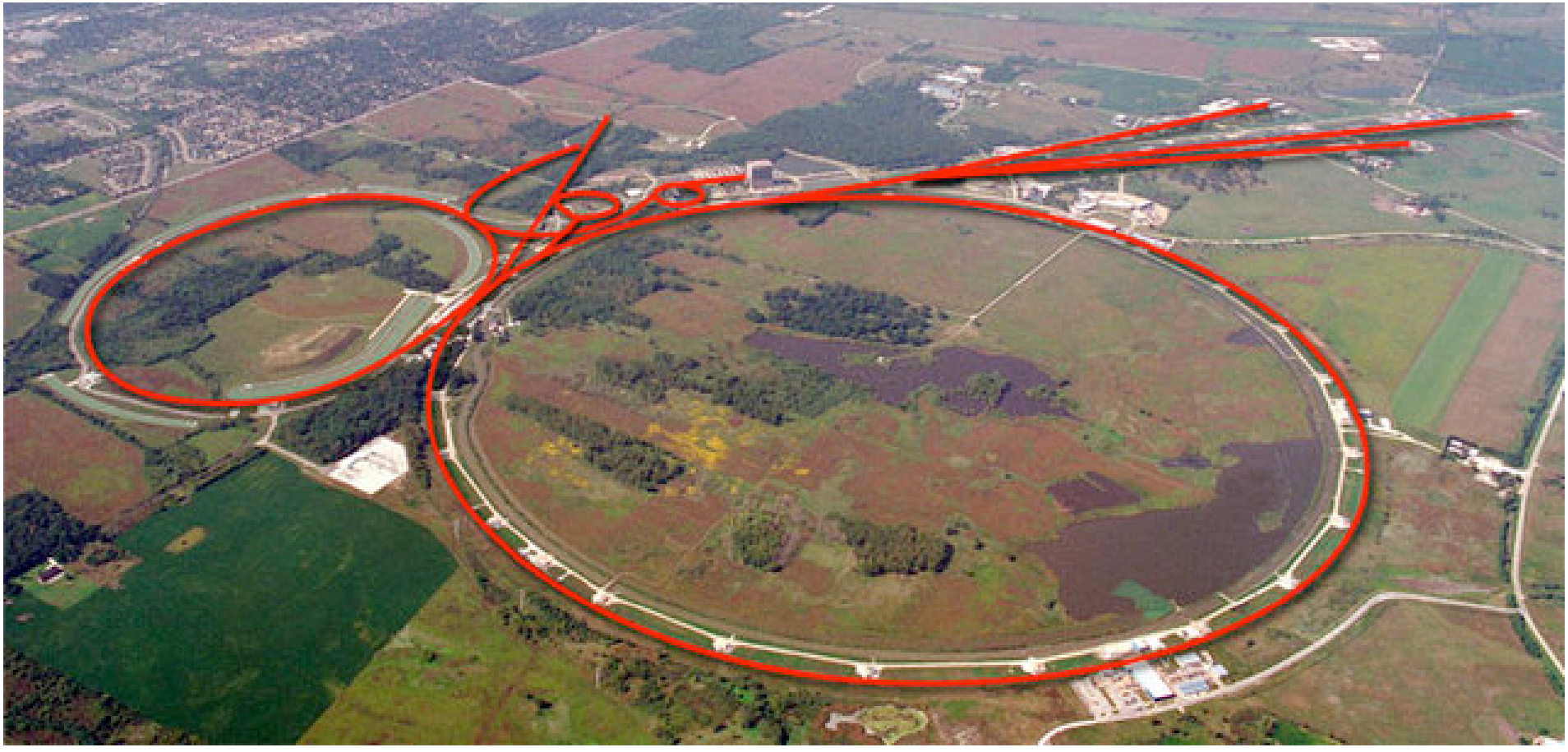


Today



25th anniversary of the first collisions in the Tevatron

CP violation in the Charm sector

- Precision measurements of CP violation probe the possible existence of New Physics beyond what is currently accessible through direct searches.
- CP violation observed so far is explained within the Standard Model and is far from sufficient to explain the matter-antimatter asymmetry of the Universe, so there must be something else...
- Until recently most CP violation measurements have been done in the area of down-quarks (s, b), so what about up-quarks? Why not look where we did not look before?
- Charm is a unique window to New Physics because it probes up-quark sector (unaccessible through t or u quarks).
- Observed D^0 mixing rate is large, consistent only with most stretched Standard Model predictions. Could this be a first hint of New Physics?

CP asymmetry in $D^0 \to \pi^+\pi^-$ decays

What do we measure?

$$A_{CP}(D^0 \to \pi^+\pi^-) = \frac{\Gamma(D^0 \to \pi^+\pi^-) - \Gamma(\overline{D}^0 \to \pi^-\pi^+)}{\Gamma(D^0 \to \pi^+\pi^-) + \Gamma(\overline{D}^0 \to \pi^-\pi^+)}$$

- CP symmetric initial state ($p\bar{p}$) ensures charge symmetric production.
- Tag flavor at production time through $D^\star \to D^0\pi_s$ decay.
- With ~ 215K candidates the expected statistical resolution is $\sim 0.2\%$.
- Small Q-value in $D^\star$ decay causes π_s to be low momentum:
  - typically in the range where detector efficiency for tracks of opposite charge is asymmetric to the level of a few percents.
- Need to suppress detector charge asymmetry by more than one order of magnitude to control systematics at $\sim 0.1\%$.
- Turns out this can be done with a very high degree of confidence using only data, no need to rely on Monte Carlo.

How are we doing it?

Combine the "raw" asymmetries of three different event samples to minimize systematic errors caused by the detector induced asymmetries:

✓ $D^\star \to D^0\pi_s \to [\pi\ \pi]\ \pi_s$ $\quad A_{CP}^{raw}(\pi\pi^\star) = A_{CP}(\pi\pi) + \delta(\pi_s)$

cancel asymmetry due to π_s^+/π_s^- different reconstruction efficiencies

✓ $D^\star \to D^0\pi_s \to [K\pi]\ \pi_s$ $\quad A_{CP}^{raw}(K\pi^\star) = A_{CP}(K\pi) + \delta(\pi_s) + \delta(K\pi)$

cancel asymmetry due to K^+/K^- different interaction with matter + possible CPV in $D^0 \to K\pi$

✓ $D^0 \to [K\pi]$ $\quad A_{CP}^{raw}(K\pi) = A_{CP}(K\pi) + \delta(K\pi)$

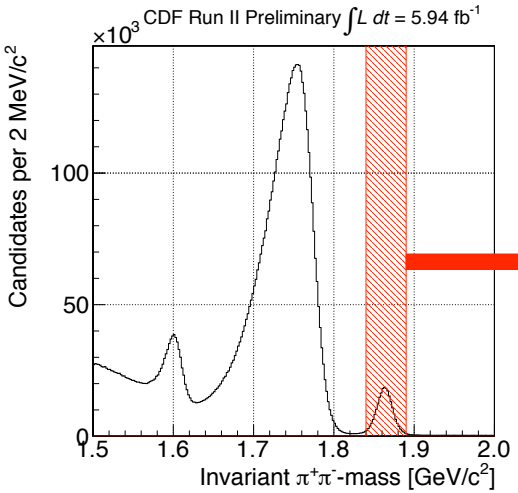
The physical A_{CP} could be extracted through the combination:

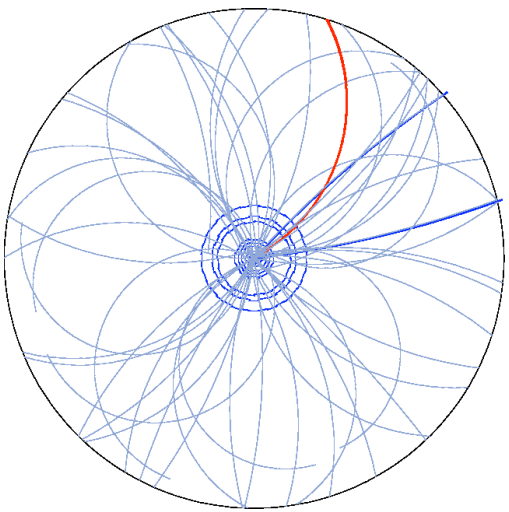
$$A_{CP}(\pi\pi) = A_{CP}^{raw}(\pi\pi^\star) - A_{CP}^{raw}(K\pi^\star) + A_{CP}^{raw}(K\pi)$$

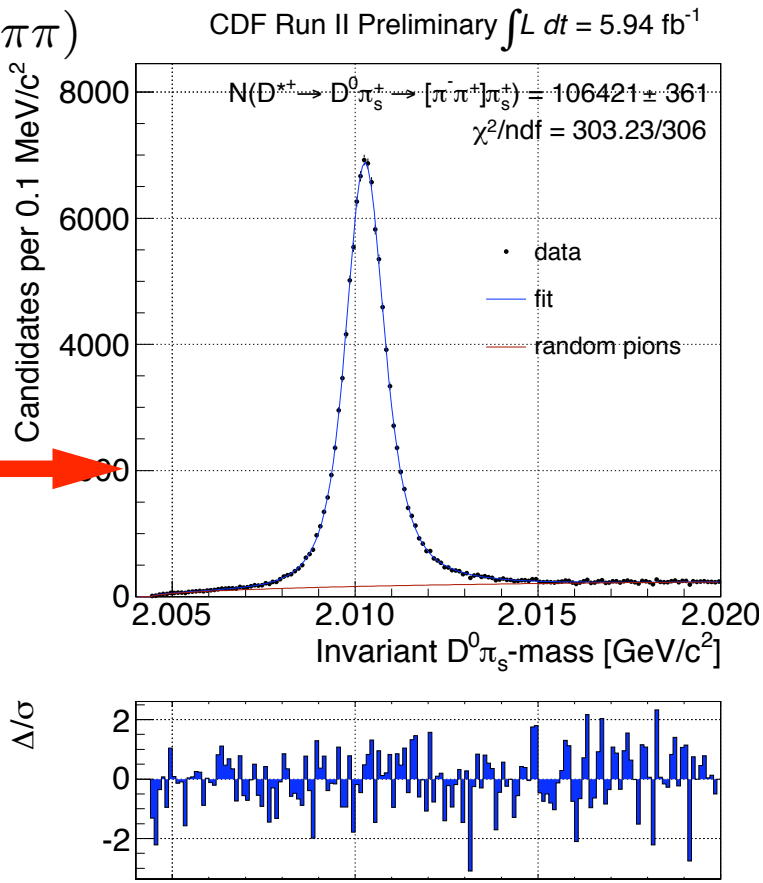
Counting $D^{\star}$-tagged $D^0 \to \pi^+\pi^-$

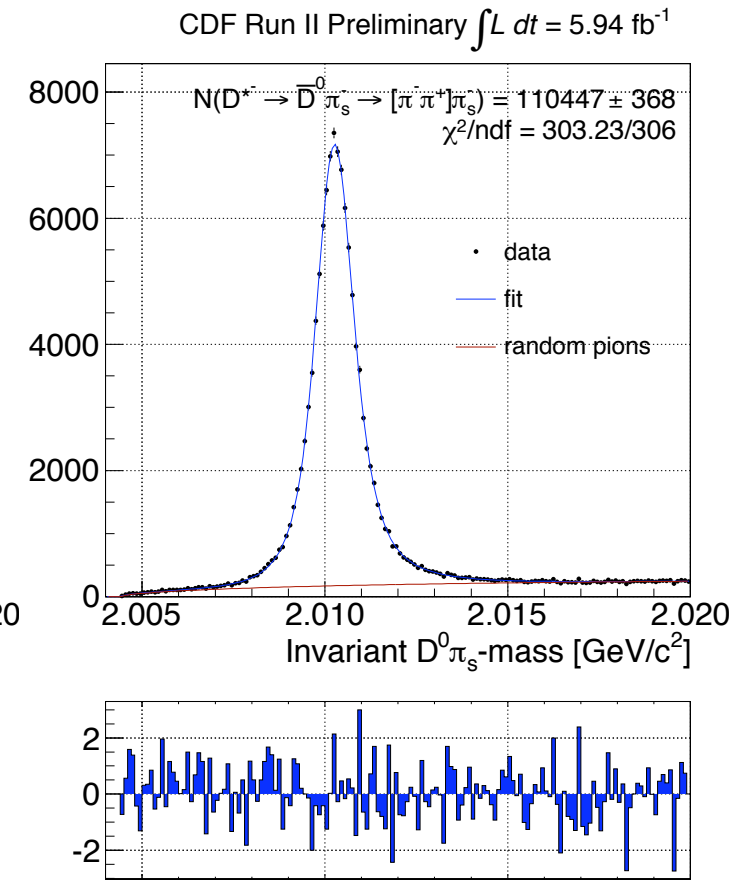
Select signal with $M(\pi\pi)$

then fit $M(D^0\pi_s)$







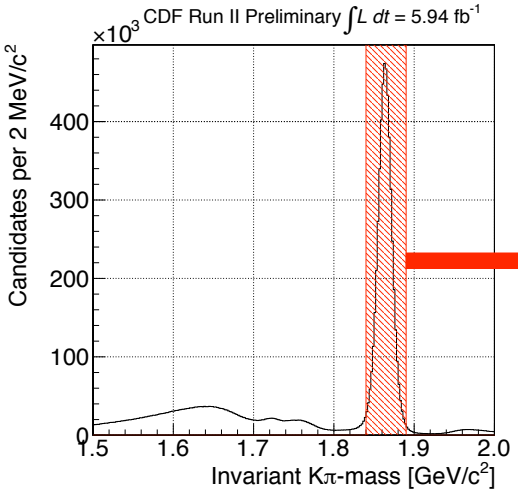


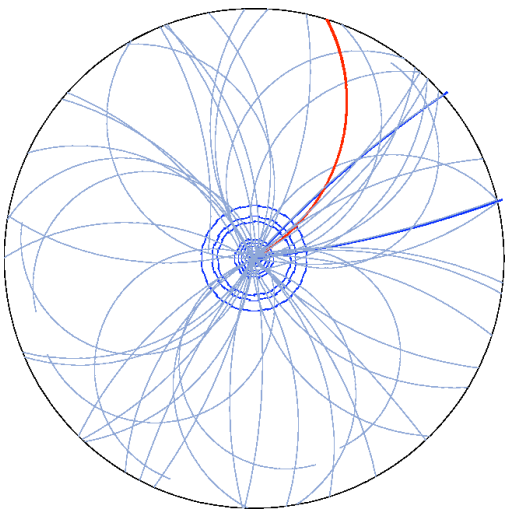
$\sim 215{\cdot}000$ $D^{\star}$-tagged $D^0 \to \pi\pi$

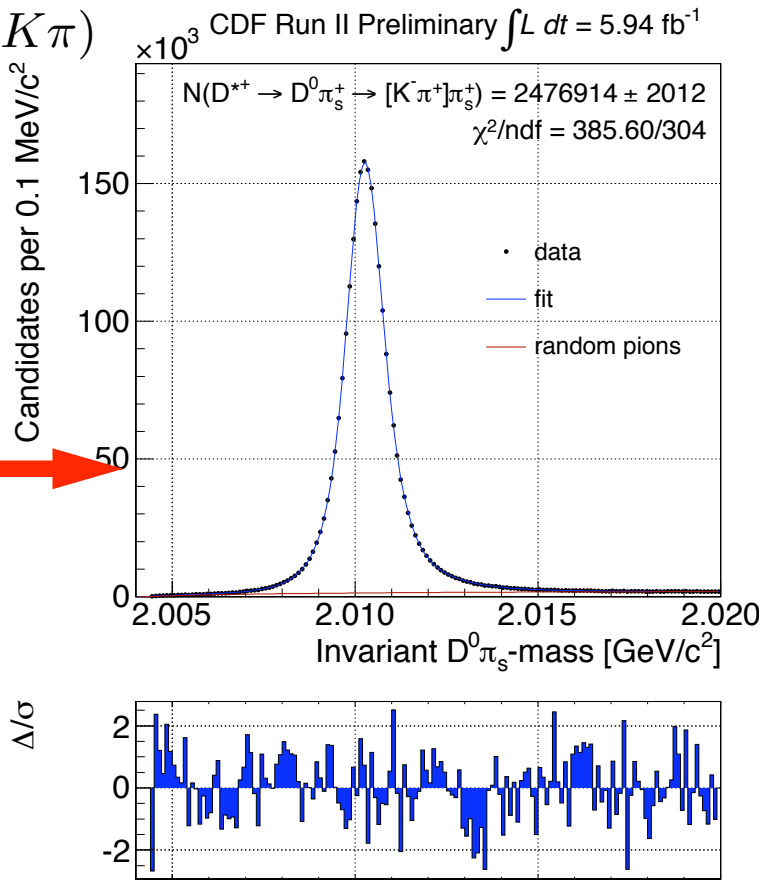
$$A_{CP}^{raw}(\pi\pi^{\star}) = (-1.86 \pm 0.23)\%$$

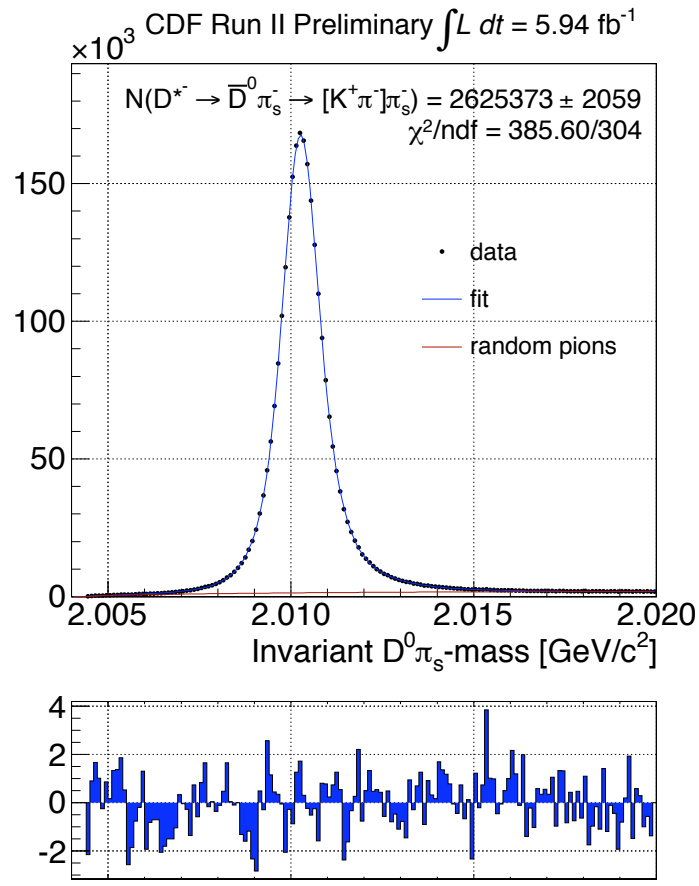
Counting $D^{\star}$-tagged $D^0 \to K^-\pi^+$

Select signal with $M(K\pi)$
then fit $M(D^0\pi_s)$





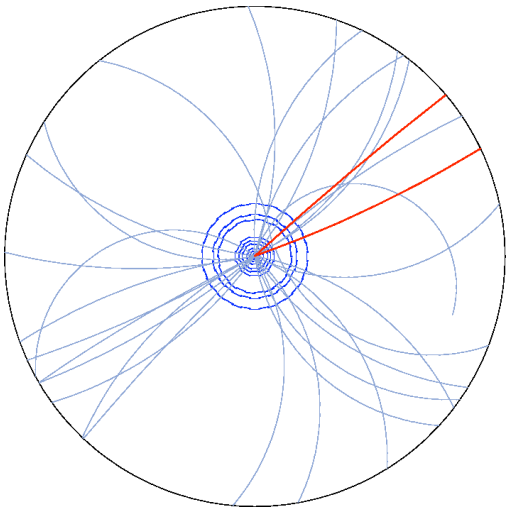


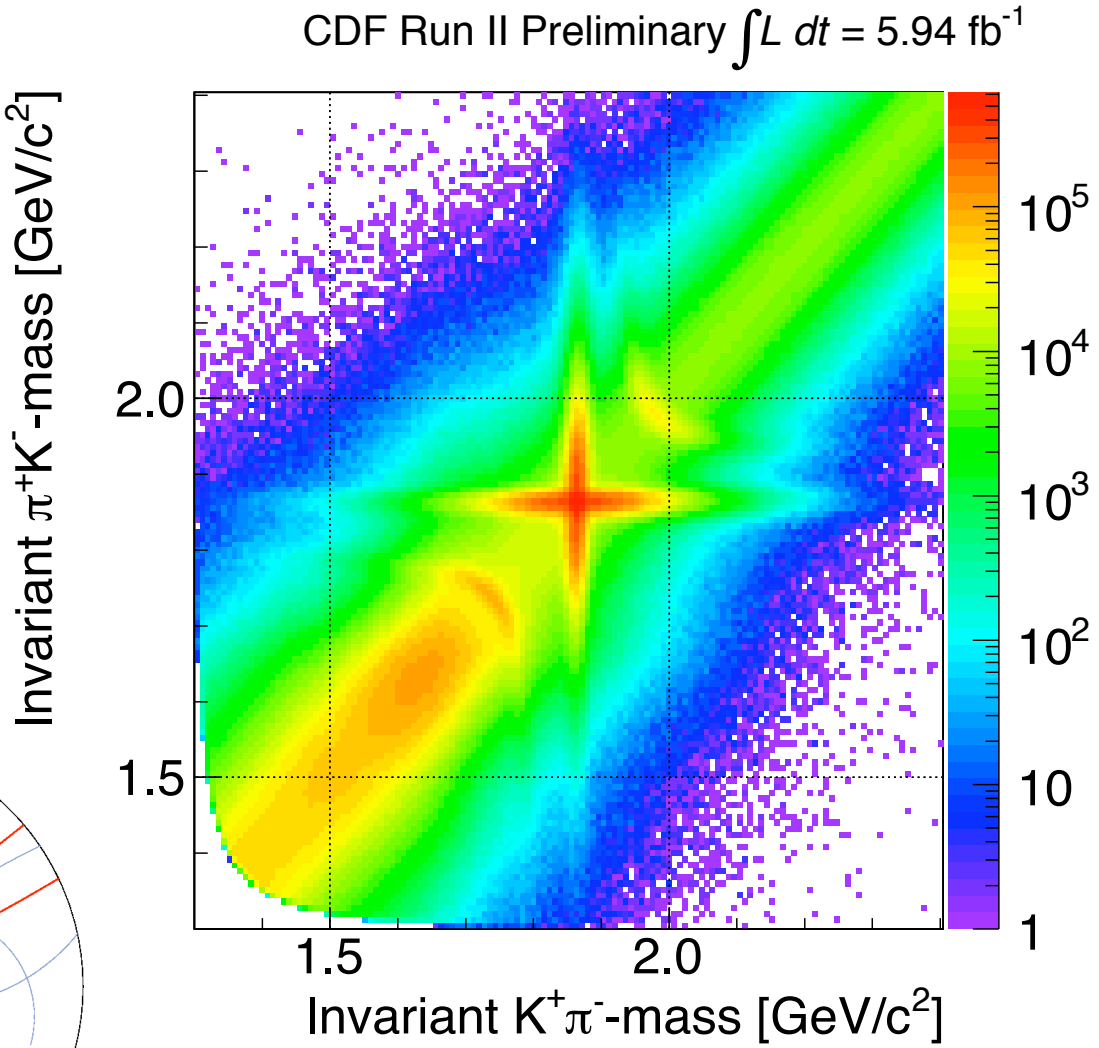


$\sim 5{\cdot}000{\cdot}000$ $D^{\star}$-tagged $D^0 \to K\pi$

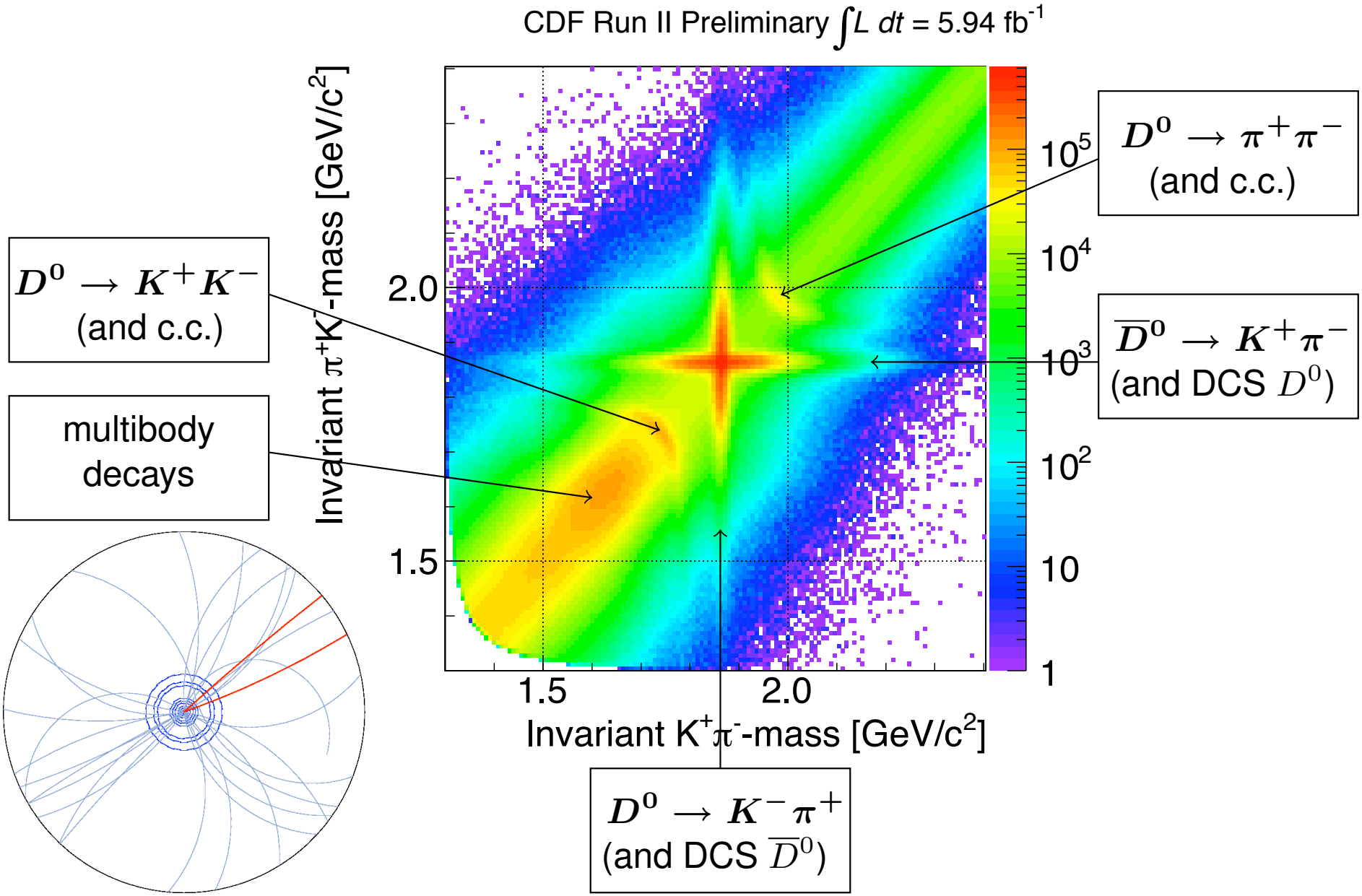
$$A_{CP}^{raw}(K\pi^{\star}) = (-2.91 \pm 0.05)\%$$

Counting untagged $D^0 \to K^-\pi^+$ (1)

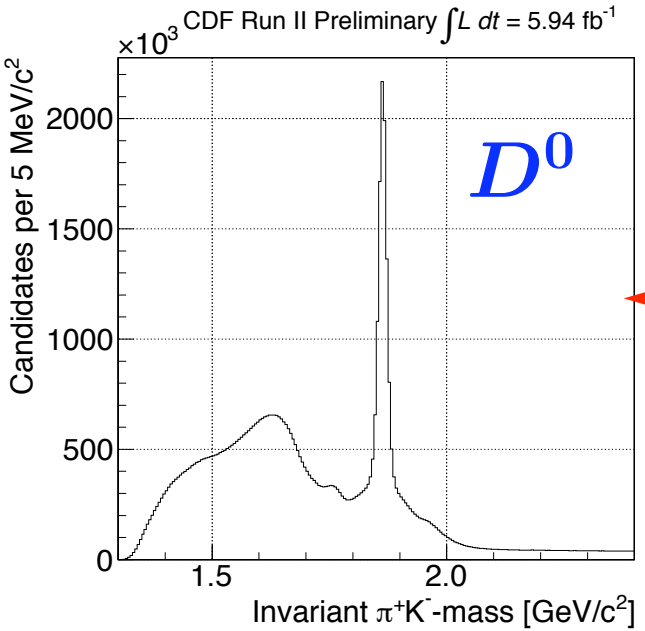


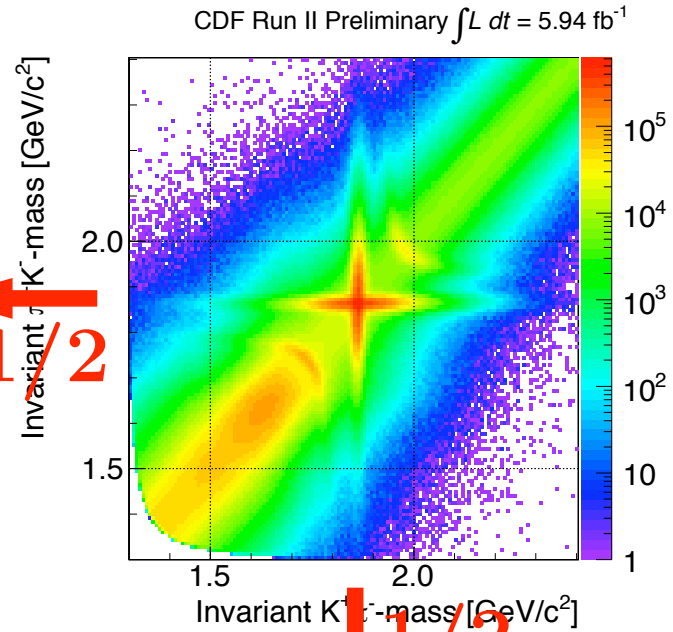


Counting untagged $D^0 \to K^-\pi^+$ (1)



Counting untagged $D^0 \to K^-\pi^+$ (1)





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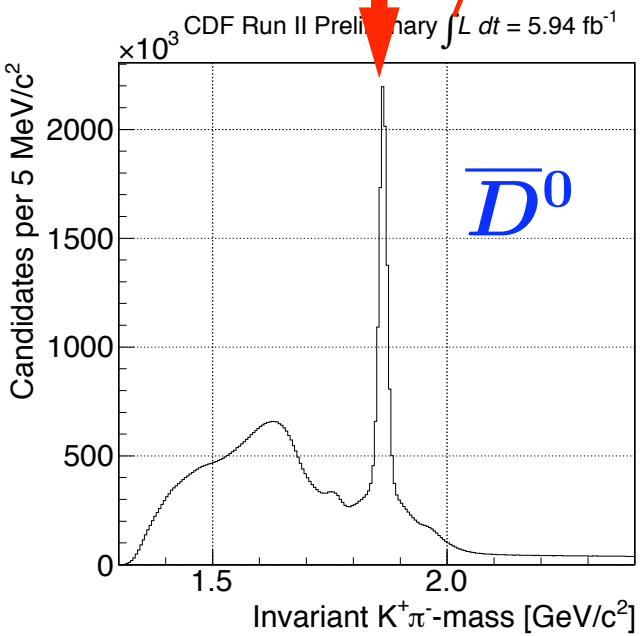
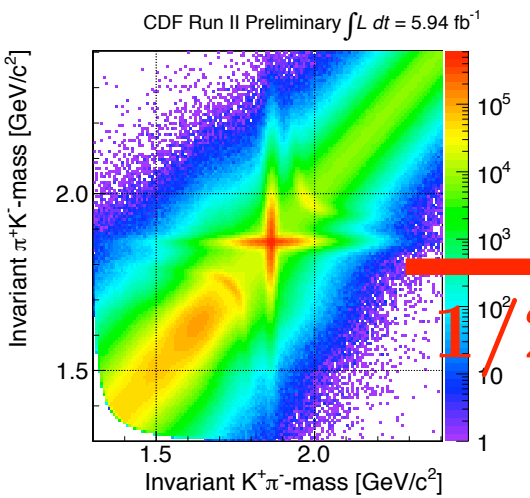


- ✓ two statistically independent samples with half the events each
- ✓ can easily afford to loose a factor of two in statistics here
- ✓ signal is in narrow peak (ignore DCS contribution)

Counting untagged $D^0 \to K^-\pi^+$ (2)



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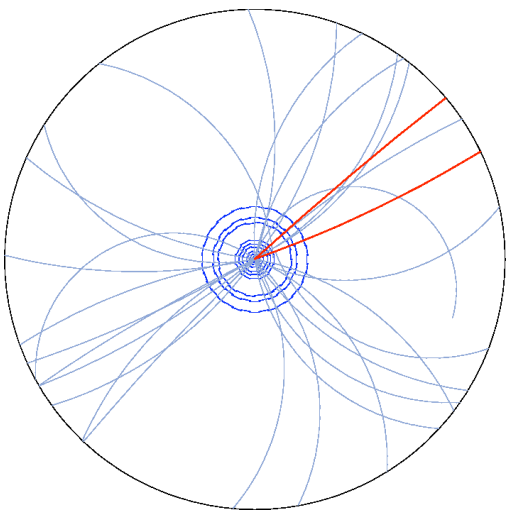
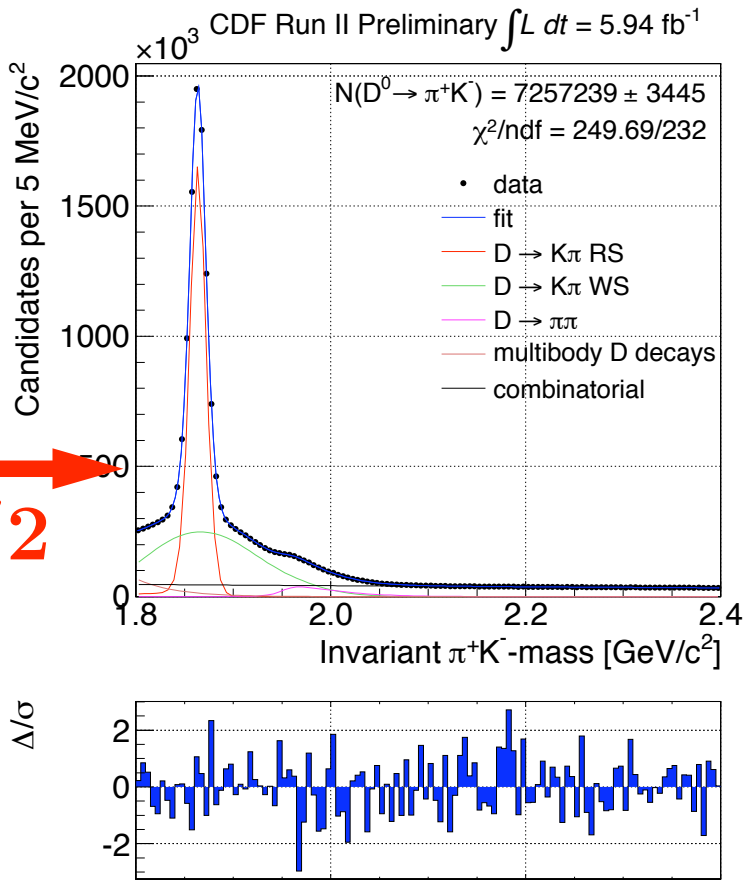
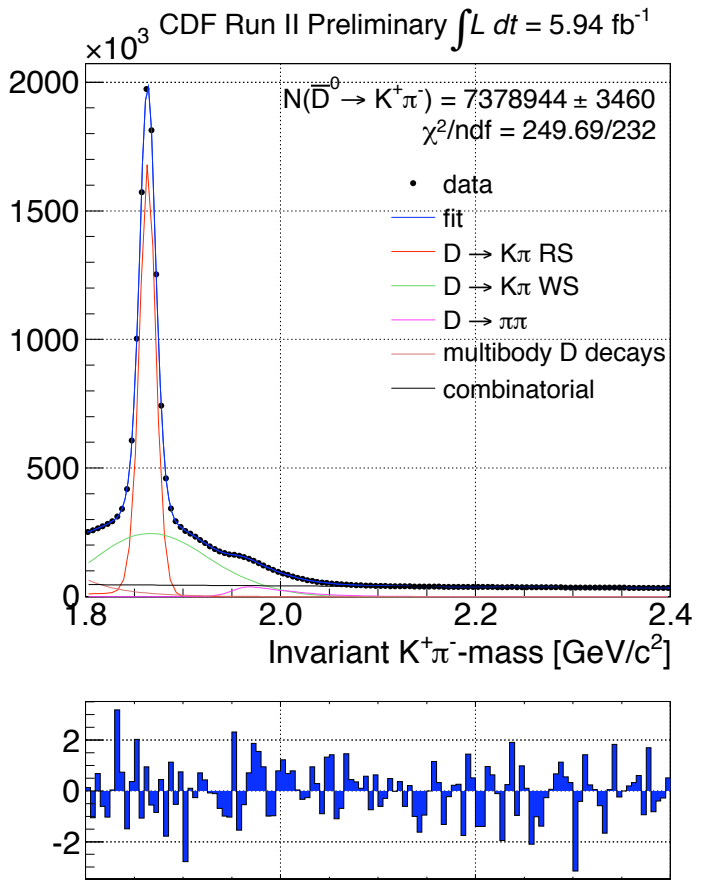






$\sim 2 \times 15{\cdot}000{\cdot}000$ untagged $D^0 \to K\pi$

$$A_{CP}^{raw}(K\pi) = (-0.83 \pm 0.03)\%$$

Systematics

Summary of all sources of systematic error:

Source of systematic uncertainty	Variation on $A_{CP}(\pi\pi)$
Approximations in the method	0.009%
Beam drag effects	0.004%
Contamination of non-prompt D^0s	0.034%
Templates used in fits	0.010%
Templates charge differences	0.098%
Asymmetries from non-subtracted backgrounds	0.018%
Imperfect sample reweighing	0.0005%
Sum in quadrature	0.105%

Final result

- In 5.94 fb^{-1} of CDF data we measure

$$A_{CP}(D^0 \to \pi^+\pi^-) = [+0.22 \pm 0.24\ (stat.) \pm 0.11\ (syst.)]\%$$

Public documentation: http://www-cdf.fnal.gov/physics/new/bottom/100916.blessed-Dpipi6.0/

- World's best measurement so far

BaBar on 386/fb $[-0.24 \pm 0.52\ (stat.) \pm 0.22\ (syst.)]\%$

Phys. Rev. Lett. **100** (2008) 061803

Belle on 540/fb $[+0.43 \pm 0.52\ (stat.) \pm 0.12\ (syst.)]\%$

Phys. Lett. **B 670** (2008) 190

- To correctly compare with B-factories we need to better understand what we measured.

Direct and indirect CPV in $D^0 \to \pi^+\pi^-$

- Time-integrated CP asymmetry

$$A_{CP}(\pi^+\pi^-) = \frac{\Gamma(D^0 \to \pi^+\pi^-) - \Gamma(\overline{D}^0 \to \pi^-\pi^+)}{\Gamma(D^0 \to \pi^+\pi^-) + \Gamma(\overline{D}^0 \to \pi^-\pi^+)},$$

  receives contribution from different amplitudes in D^0 and $\overline{D}^0$ decays (direct CP violation) but also from mixing induced effects (indirect CP violation).

- The latter source produces a time-dependent asymmetry that persists when integrated over time.

- Since flavour mixing parameters are small in the charm sector, at first order, the measured integrated asymmetry is the linear combination of the two contributions

$$A_{CP}(\pi^+\pi^-) \approx a_{CP}^{dir} + \frac{\langle t \rangle}{\tau} a_{CP}^{ind}$$

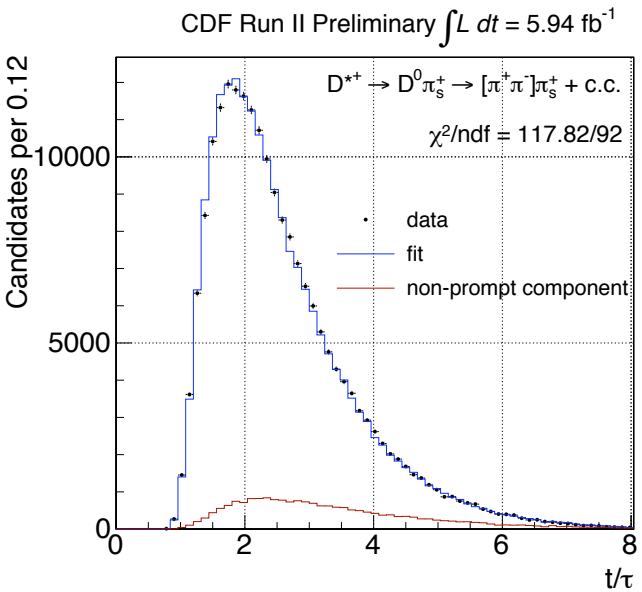
  where t/τ is the proper decay time in unit of D^0 lifetime.

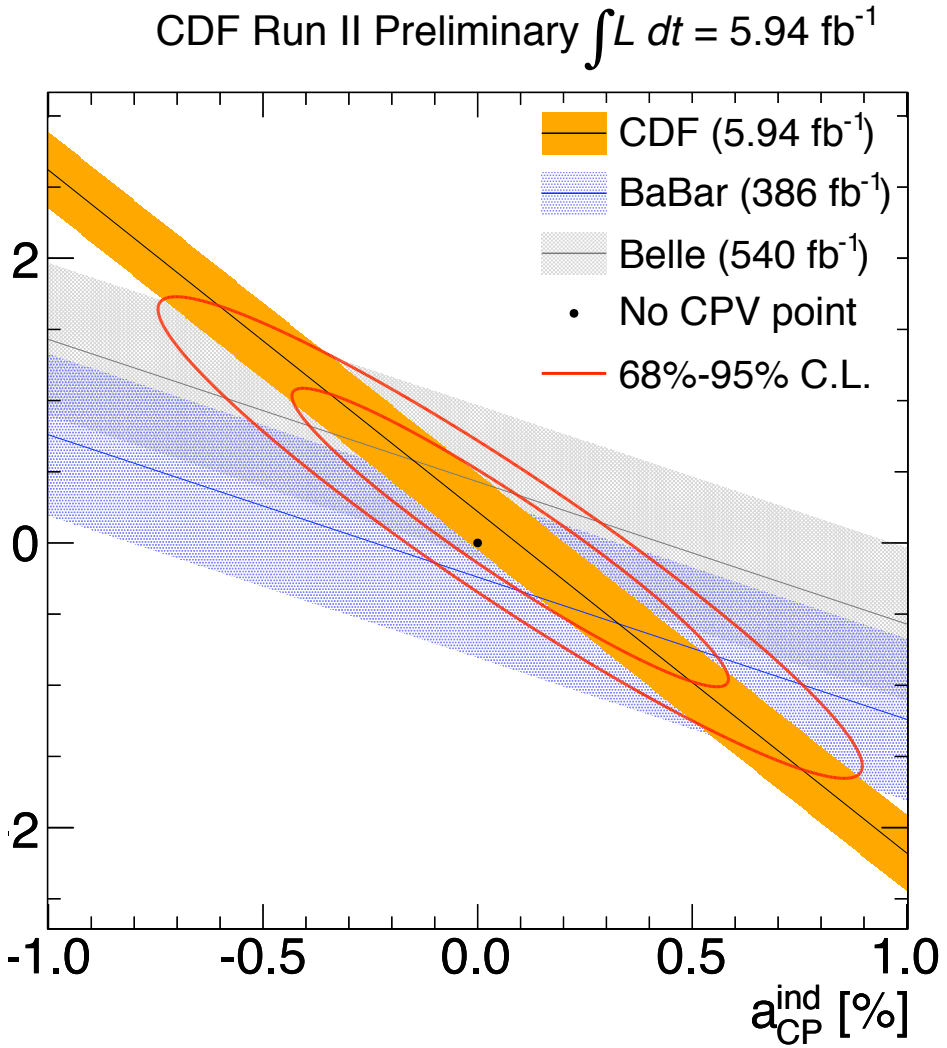
- The measurement describes a straight band in the plane $(a_{CP}^{ind}, a_{CP}^{dir})$ with slope given by the average proper time of the $D^0 \to \pi^+\pi^-$ sample.

Comparing with B-factories (1)

CDF trigger bias proper time distribution towards higher values

$\langle t \rangle \approx 2.40\,\tau$



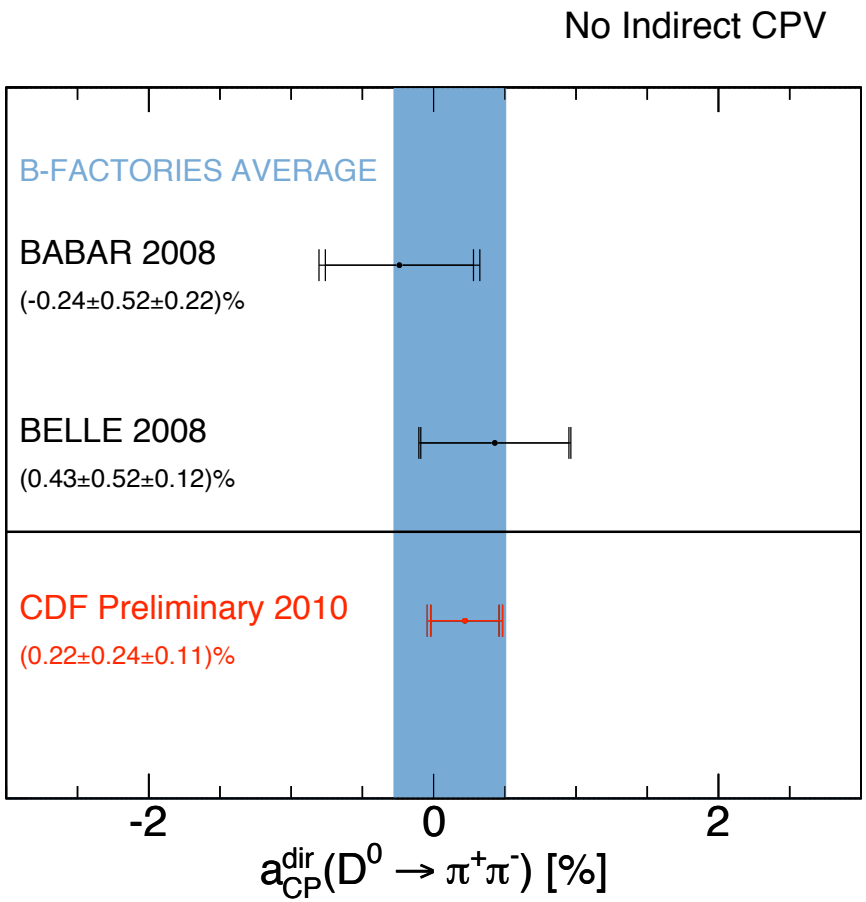


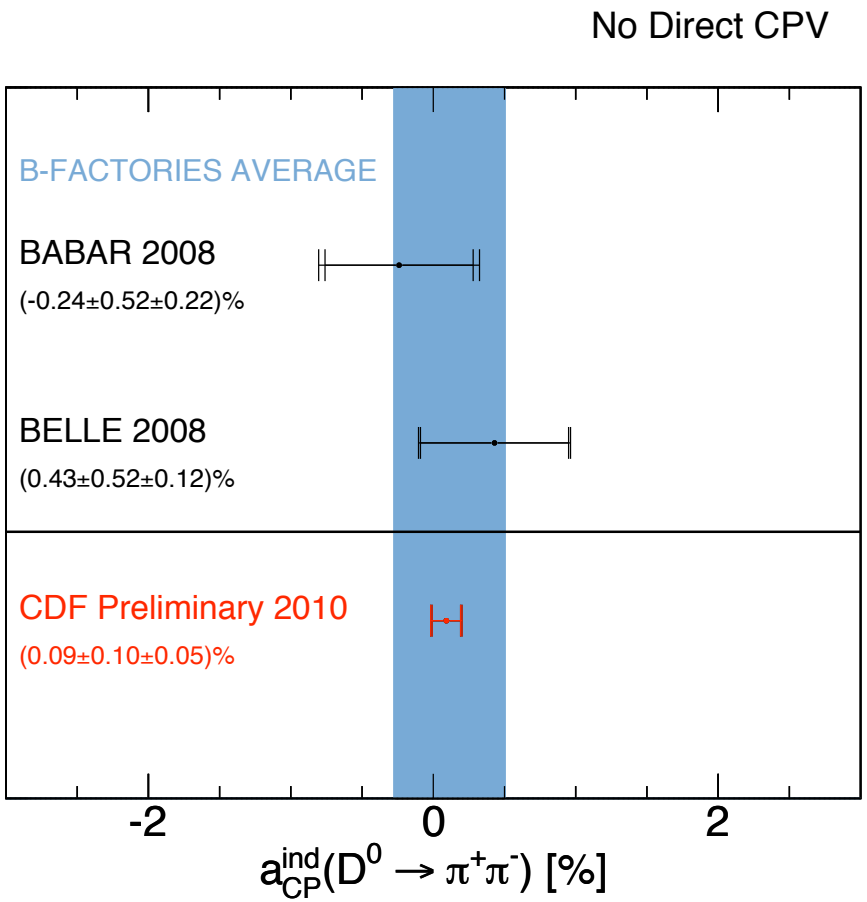
at B-factories

$\langle t \rangle \approx \tau$

combination assuming gaussian errors

Comparing with B-factories (2)





Conclusions

- Most precise A_{CP} measurement ever in the Charm sector
- We have now enough precision to probe the Charm sector for new physics in a significant way
- High precision measurements competitive or even superior to the B-factories are possible at the Tevatron
- Still limited by statistics and will improve with integrated luminosity ($5.9 \rightarrow 10 \rightarrow 20$ fb^{-1}?)
- Short term prospect: $D^0 \rightarrow K^+K^-$